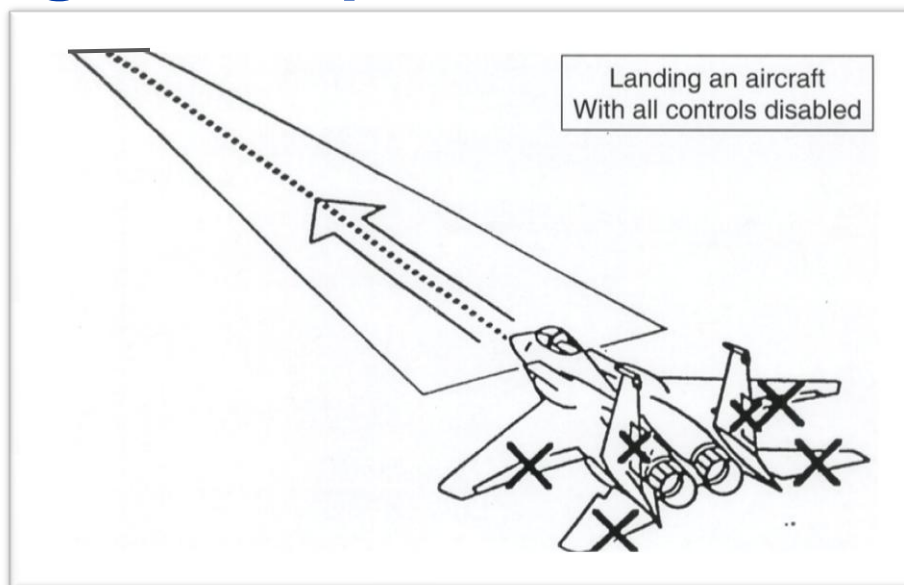


Research & Technology

Integrated Flight / Propulsion Control Applications



3rd NASA GRC Propulsion Controls and Diagnostics Workshop February 28 – March 1, 2012 Cleveland, Ohio

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Jim Urnes, Sr.
The Boeing Company
St. Louis, MO
james.m.urnes-sr@boeing.com

Agenda

I. Programs on Integrated Flight / Propulsion Control

1. Navy Approach Power Compensation Systems
2. NASA Propulsion Controlled Aircraft
 - Fighter
 - Transport
3. Yaw stabilization of a Transport using Propulsion Control
4. Increased Power Response for Runway Incursion

II. Projects for Integrated Flight / Propulsion Control

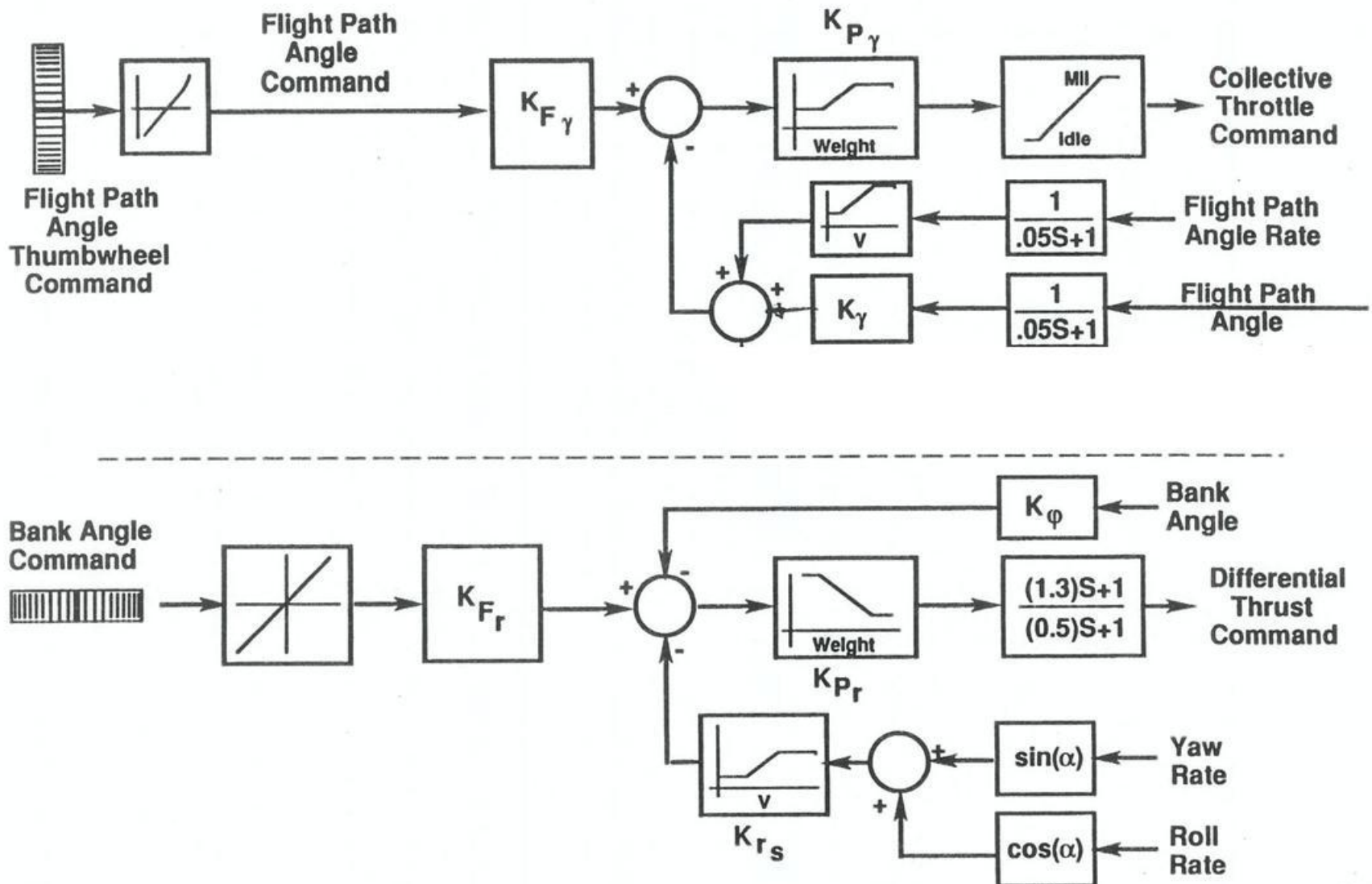
Navy Approach Power Compensation System (APCS)

- **Navy tactical aircraft engines have rapid dynamic response**
 - Carrier approach requires fast thrust response
 - Assistance to pilot via auto throttle (APCS) systems
- **APCS control gains are very high**
 - Controls aircraft angle of attack to reference angle ± 0.5 degrees
 - Features high angle of attack gain offset by high normal acceleration gain
 - Control further augmented by stabilizer command to increase thrust response
- **APCS control gains change when Automatic Carrier Landing Flight mode is engaged**
 - Thrust response critical to successful flight path maneuvering

NASA Propulsion Controlled Aircraft (PCA) Program

- **Program initiated after United Flight 262 lost all flight control and landed at Sioux City, Iowa**
 - Direct throttle control used, very difficult to control Phugoid and Dutch Roll Oscillations
- **Initial phase developed a PCA flight mode for the NASA F-15**
 - P&W 1128 engines
 - Lead compensation applied in roll/yaw to increase thrust dynamic response
 - Thumbwheel controller for pitch and roll/yaw control instead of stick
 - Flight commands directly to engine controllers
 - No backdrive to throttles
 - Special HUD display to counter large lag in flight
- **Successful flight test results for navigation, letdown and landing with PCA**
- **Next phase conducted on MD-11 transport with good flight test results**

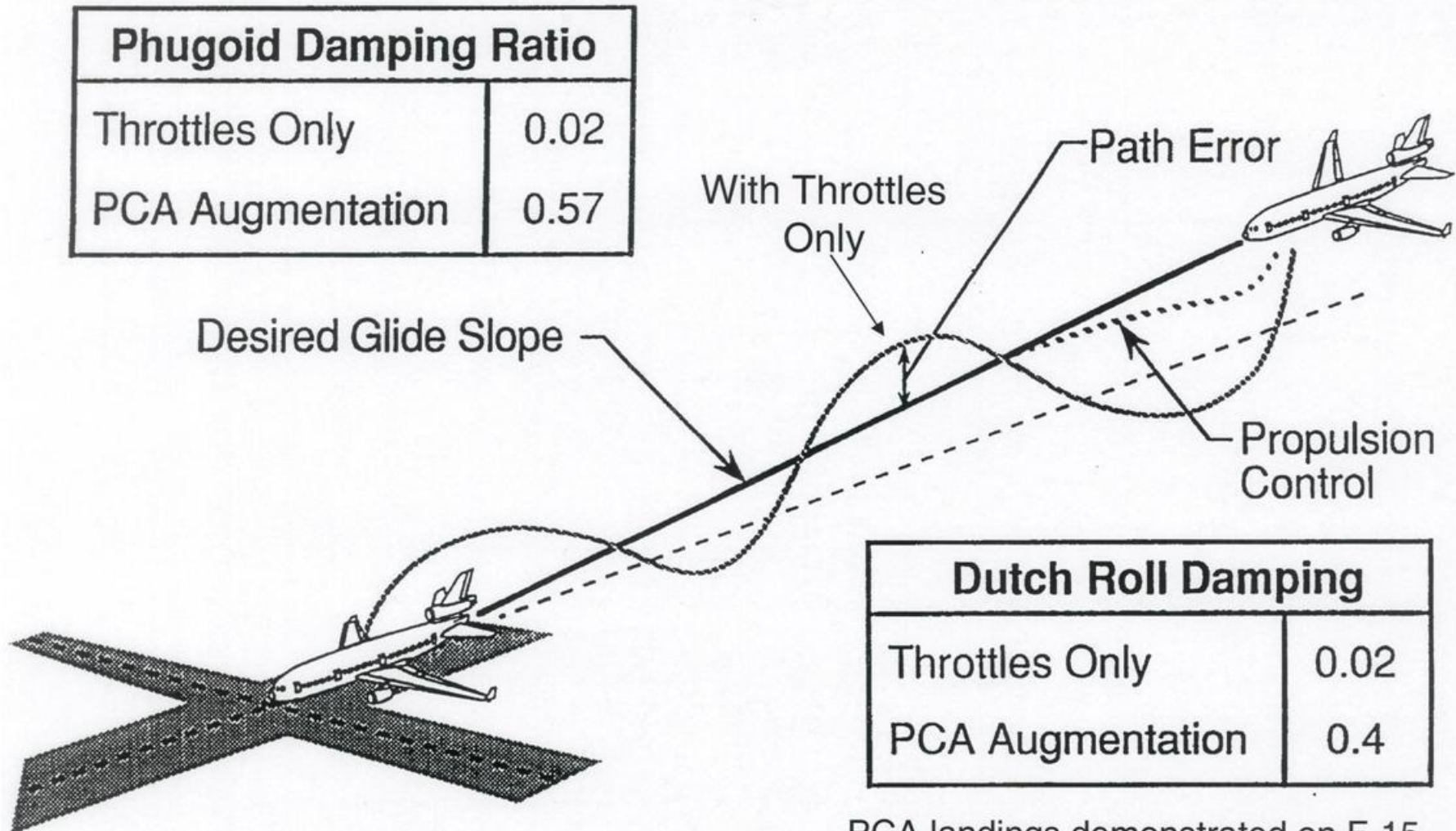
F-15 PCA Integrated Control Laws



Propulsion Control Provides Necessary Path Damping Improvement

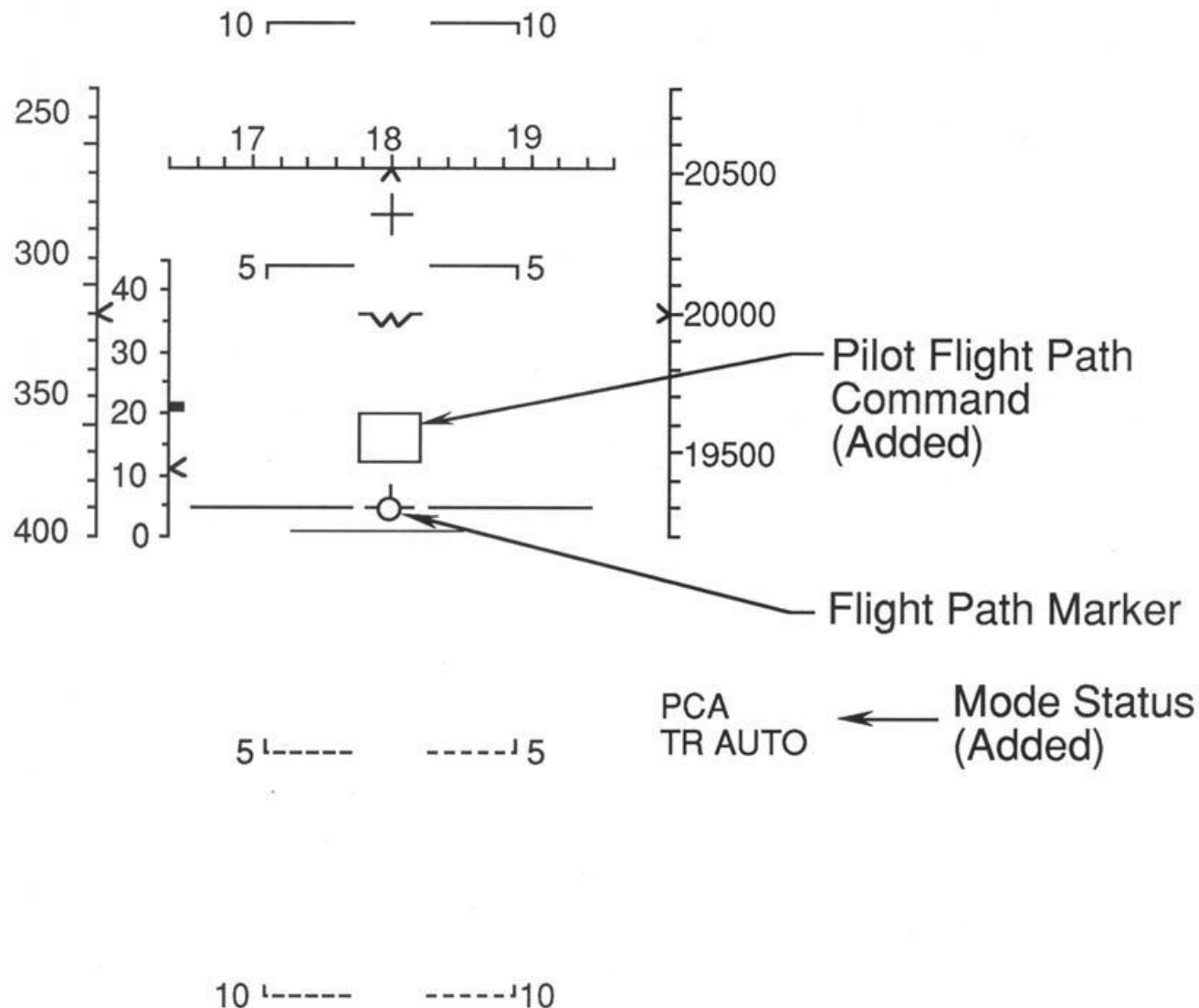
Flight & Systems Technology | Boeing Research & Technology

PSST | Vehicle Systems Technology

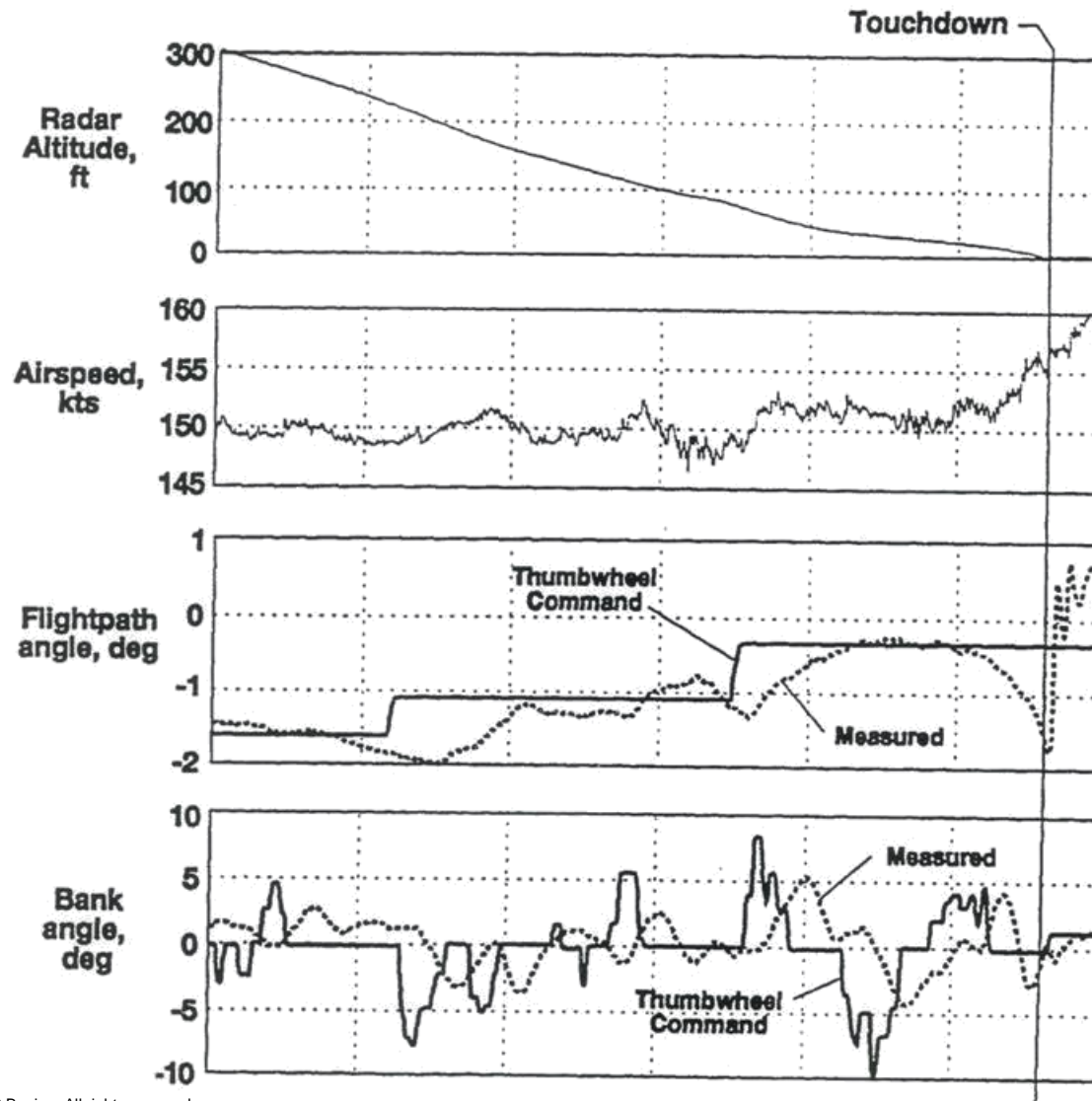


PCA landings demonstrated on F-15 and MD-11 aircraft at Edwards AFB

HUD Display for Propulsion Controlled Aircraft



F-15 First PCA Landing



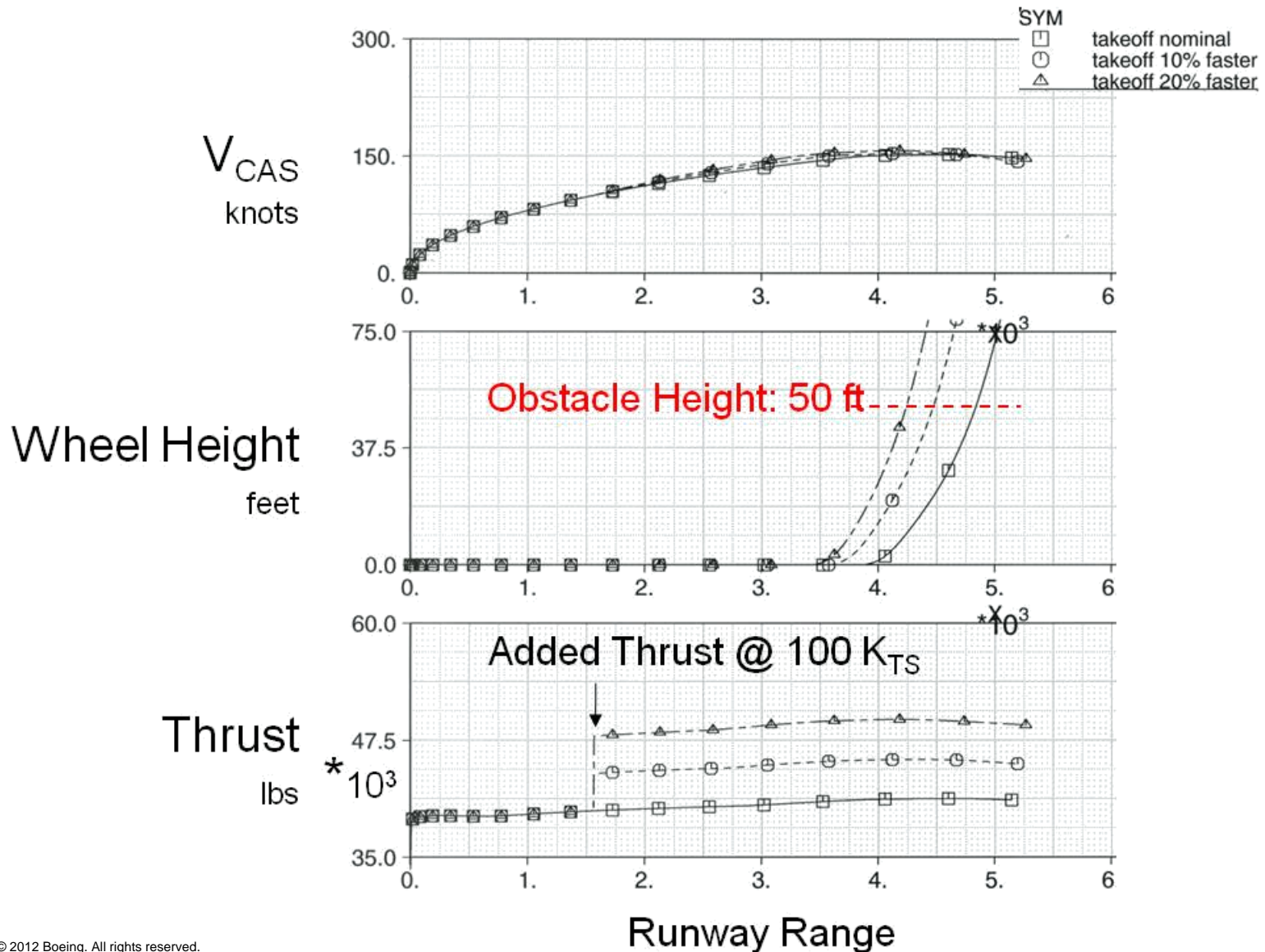
Landing
Flown by
Gordon Fullerton
NASA F-15
Test Pilot

FASTER Engine Response Program

Tests to be Conducted on a Transport Flight Simulator

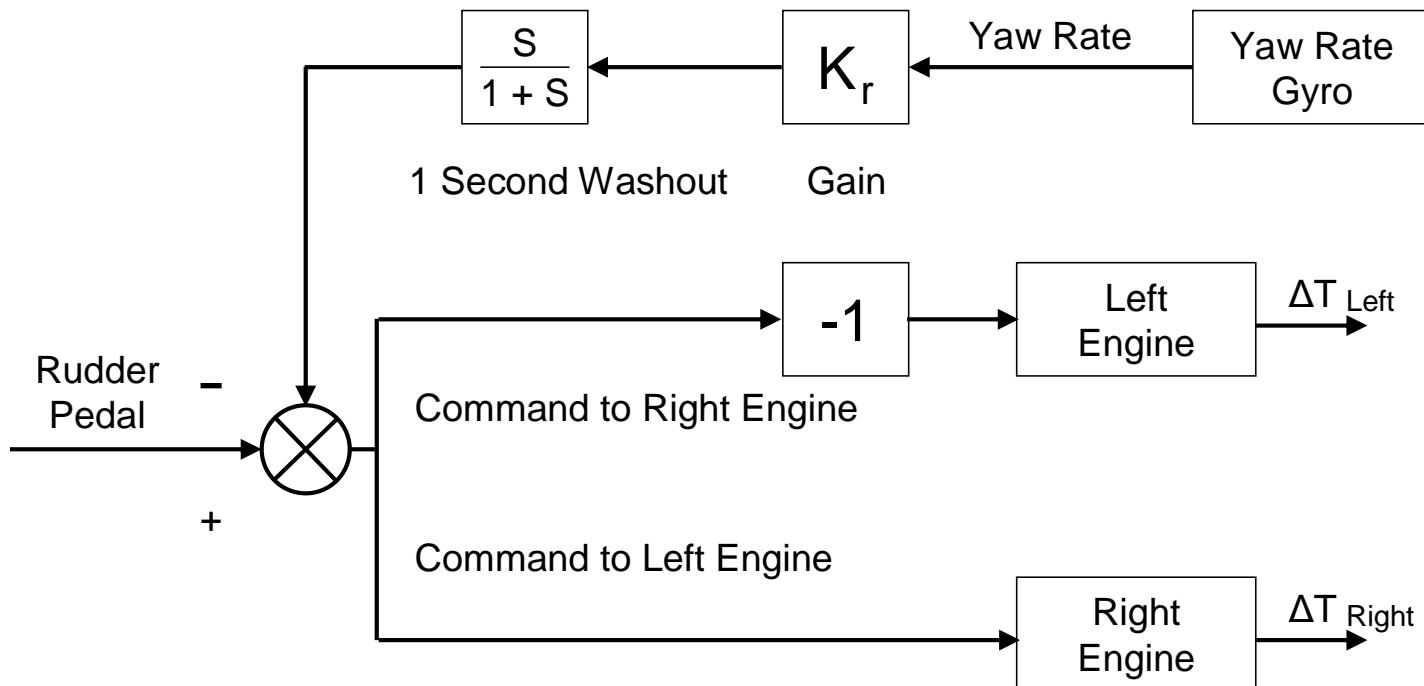
1. Runway incursion: Aircraft is on Takeoff roll in weather or night conditions when another aircraft enters the runway
 - Evaluate nominal and FASTER engine response
 - Determine flight path that avoids intruding vehicle
2. Rudder failure: Use engine differential thrust to replace rudder yaw control.
 - Rudder fails during let-down to final approach
 - Evaluate control to landing touchdown

Shortened Takeoff Using Added Thrust



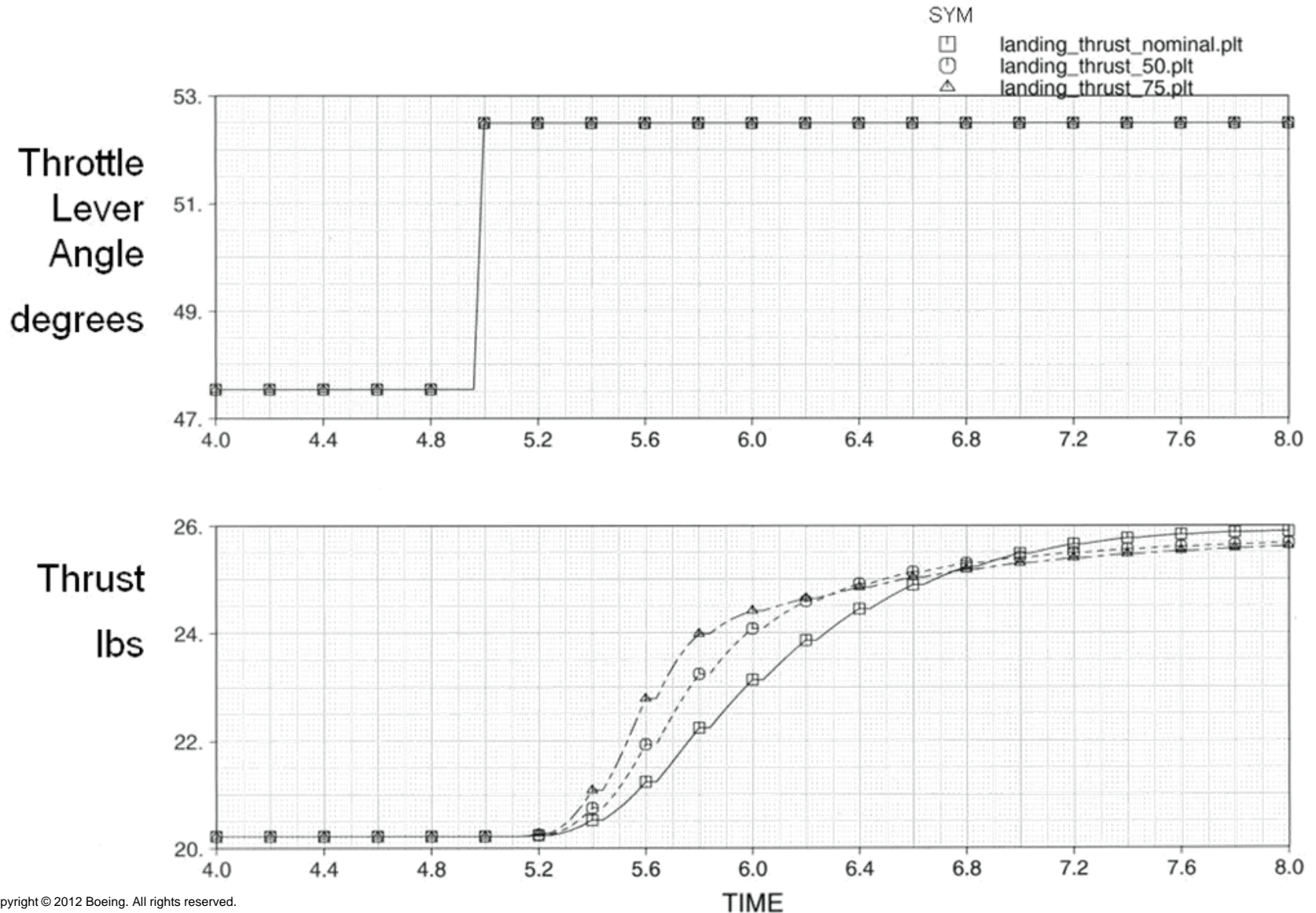
Directional Control Using Propulsion Changes

Thrust Augmentation for Increasing Directional Stability: Control Law Diagram

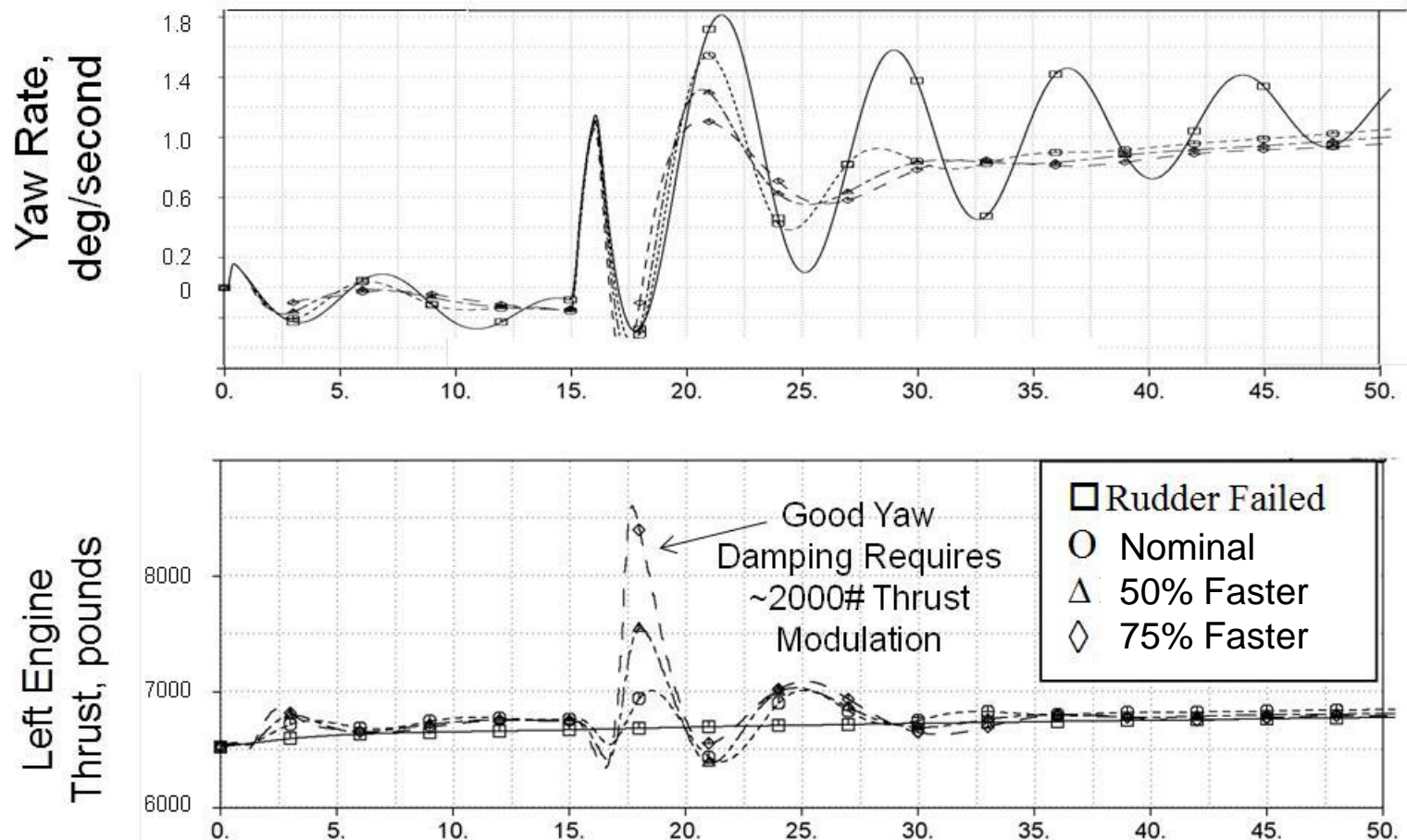


Select gain K_r to provide minimum Gain Margin of 6db and minimum Phase Margin of 30 degrees

Landing with Engines Having Faster Response



Directional Control using Propulsion Effectors



Directional Stability with Faster Engine Response

Damping of the Dutch Roll Mode using Different Engine Model Dynamics

CONFIGURATION	DAMPING RATIO
Rudder Failed: No Augmentation	.05
Nominal Engine Dynamics	.2
50% Reduction in Engine Time Constant	.3
75% Reduction in Engine Time Constant	.4

Summary

1. Emergency increase in thrust a strong advantage for runway incursion / obstacle avoidance
Concern: P&W 20% Mil Power increase feasible, does increase temperature in the engine, can shorten engine life
2. Engine dynamics can be adjusted to provide emergency directional control
Concern: F-117 engine can be controlled for faster response, does increase engine temperature
3. Test pilot ratings for C-17 transport flight simulator evaluation show performance advantage

Boeing Report 2011P0014: "Piloted Flight Simulator Evaluation of Fast Engine Response," dated July 22, 2011

Development Programs

1. Control for Loss of Vertical Tail or Rudder
2. Directional Control for Tailless Aircraft Designs
3. Prevention of Loss of Control Accidents
4. Recovery from Loss of Control Conditions
5. Green Aircraft Flight Research Projects

Safety Development: Propulsion Control to Recover Loss of Directional Stability

Problem addressed: Loss of vertical stabilizer and rudder

Possible Solution: Maximize engine dynamic response.
Use thrust changes to stabilize the damaged aircraft.

Flight Development:

1. Use opposite rudder to destabilize directional control
2. Enhance engine response for FASTER acceleration
3. Command differential thrust to establish directional stability
4. Evaluate on flight simulators: Tactical and Transport aircraft
5. Conduct flight development program

Flight Demonstration: Directional Control for Tailless Vehicles

The Problem:

- Large tailless air vehicles use split ailerons / flaps for directional control and trim
- This leads to increased drag

Possible Solution:

- Use differential thrust commands to directionally control the vehicle in place of the split ailerons / flaps
- Close coupled engine locations on X-48B, X-48C needs to be evaluated: small moment arm for thrust changes
- F/A-18 #853 has similar close-coupled engine location, use as development step for X-48 and other propulsion control applications

A Safety System to Prevent Loss of Control Aircraft Accidents

Loss-of-Control Accidents are the #1 source of commercial aircraft accidents.

- Loss-of-control accidents have been due to pilot inattention or distractions that permit the aircraft to enter large and mostly uncharted flight attitudes, and the pilot has little knowledge, skill, or training to recover and the aircraft crashes.
- This safety system incorporates engine thrust changes to autonomously establish boundary limits to bank angle, angle of attack and sideslip and thus keep the aircraft always inside of a safe maneuvering envelope.
- Provides an aircraft product that has built-in protection against loss-of-control as a major safety feature.
- This safety system does not interfere with the conventional control available to the pilot.

Solution: Don't let the aircraft enter non-recoverable flight envelope conditions. Build the protection envelope into the aircraft systems

Roll Attitude Excursions and the Attitude at which Pilot Inputs were Initiated

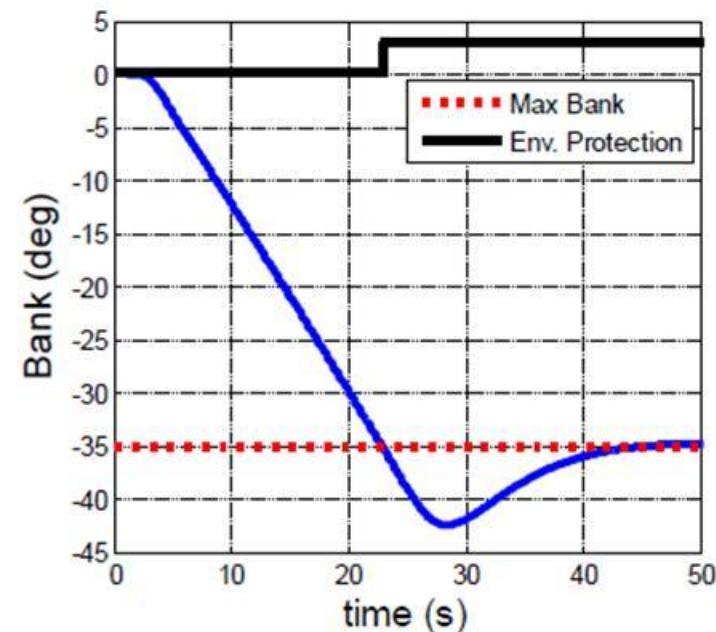
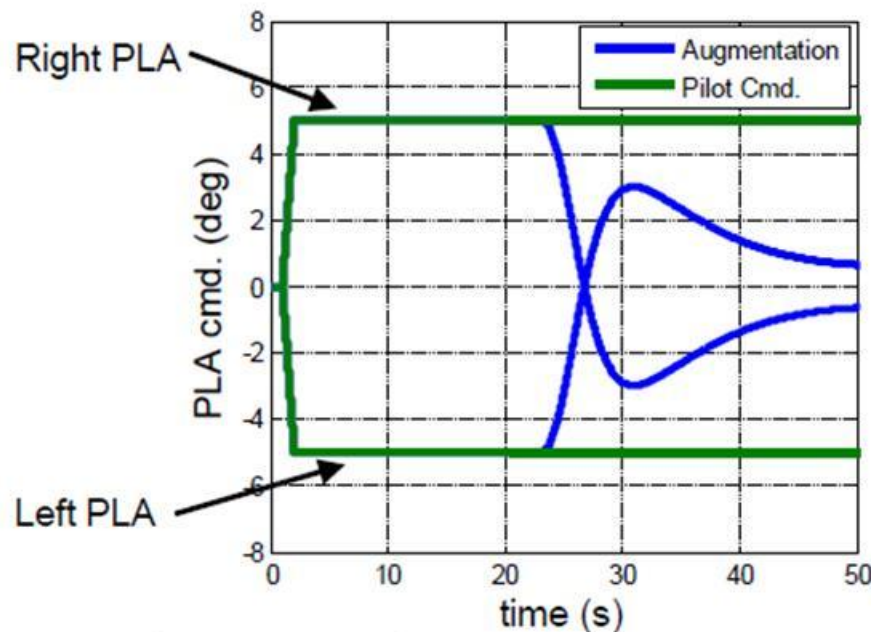
Event	Airplane	Attitude when recovery attempt was initiated*	Attitude goes to	Roll rate **
Perm, Russia	737-500	30° L	>270° L; 65° ND	40° in 30 sec
Douala, Cameroon	737-800	34° R	115° R	2°/sec to 35°
Sulawesi, Indonesia	737-400	35° R	100° R; 60° ND	1°/sec to 35°
Sochi, Russia	A320	--		
Sharm el-Sheikh, Egypt	737-300	30° R	>60° R; ND	1-2°/sec to 40°
Irkutsk, Russia	Tu154 M	45° L	>70° L; ND	above threshold
Bahrain	A320	--		
Zurich, Switzerland	Saab 340B	no recovery		2-5°/sec
London	747-200	no recovery		
Hsin-Chu, Taiwan	Saab 340B	48° R; 8° ND	??	sub-threshold
Khabarovsk, Russia	Tu154	40° R	80° R	<1°/sec for 41 sec
Charlotte, USA	DC-9-31	--		
Mezhduretshensk, Russia	A310-300	50° R	90° R	initially 1°/sec
Guilin, China	737-300	50° R	155° R	1-2°/sec
Tucuti, Panama	737-200	insufficient data		
Toledo, USA	DC-8	60° L; ND	80° L; 30° ND	??
Belvidere, USA	Convair 580	no recovery		sub-threshold

* Approximations of attitude at a particular point

** Threshold for perception of roll rate $\approx 2^\circ/\text{sec}$

Thrust Augmentation Limits the Aircraft Bank Angle

- **Bank Angle Limiting Simulation Scenario:**
- Throttle split of 10 deg. differential induces unwanted bank excursion.
- Bank angle increases
- When max bank angle is exceeded, thrust augmentation drives bank angle back to the boundary limit value



Recovery from Loss of Control Conditions

Objective: Evaluate propulsion changes to effect control for flight path recovery from large upset conditions

Advantages: Engine thrust changes more effective than control surface inputs at extreme Angle of Attack

Large structure loads needed to force recovery can be handled by engine pylon / wing structure

Needed: Control laws for recovery

Pilot cue or display of recovery commands

Keep engines operating at extreme inlet distortion conditions

Special mode in engine controller automatically activated

Green Airplane Flight Research Projects

1. Engine controller research: Link to research flight control
 - Permits in-flight evaluation
 - Enables multiple modes for engine control
2. Fuel and emissions reduction:
 - Prime objective: reduce fuel use and emissions
 - Flight path noise reduction
 - UAV performance improvement
3. Adaptive engine control
 - Minimize emissions
 - Reduce fuel consumption
 - Automatic activation of engine safety control modes

F/A-18 Research Flight Control System with Engine Controller Research Capability

Flight & Systems Technology | Boeing Research & Technology

PSST | Vehicle Systems Technology

